UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER III
SESSION 2018/2019

COURSE NAME	:	MASS AND ENERGY BALANCE
COURSE CODE	:	DAK 22903
PROGRAMME CODE	:	DAK
EXAMINATION DATE	:	AUGUST 2019
DURATION	:	3 HOURS
INSTRUCTION	:	ANSWER **FIVE (5)** QUESTIONS ONLY

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THIS QUESTION PAPER CONSISTS OF **NINE (9)** PAGES

Q1 (a) (i) State **four (4)** basic dimensions of units.

(4 marks)

(ii) Distinguish between density and specific volumes.

(4 marks)

(b) Express the dimensions for the parameters below using the symbol of M, L and T.

(i) Force
(ii) Pressure

(2 marks)

(c) Convert the values below into their equivalent SI units.

(i) 57 $lbm.ft/min^2$
(ii) 1 $gram/cm^3$

(4 marks)

(d) If a mixture of gases contains 7.50 g of H_2, 3.25 g of O_2, and 5.55 g of N_2, calculate the mole fraction of each gas. Given that, H = 1 g/mol, O = 16 g/mol, N = 14 g/mol.

(6 marks)

Q2 (a) Explain **four (4)** general separation techniques.

(8 marks)

(b) State whether the statements below is true or false.

(i) There are total of five (5) types of general separation techniques.
(ii) Separation using a solid agent can be done via absorption process.
(iii) Distillation is preferred when the differences of volatility among the components in are not sufficiently large.
(iv) Electrical force field is also considered as one of a separating agent.

(4 marks)

(c) 2500 kg/h of a mixture of benzene and toluene containing 75% benzene by mass is separated into two fractions. The mass flow rate of benzene in the top stream is 550kg/h and that of toluene in the bottom stream is 475kg/h.

(i) Draw and label a flowchart of the process.

(2 marks)

(ii) Calculate the unknown component flow rates.

(6 marks)

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Q3 (a) State **two (2)** purpose of constructing a mass balance diagram.

(4 marks)

(b) Candy production started when a flavored sugar solution is initially dried using a single evaporator (E), and followed by two crystallizers (C_1 and C_2). The process starts when 3000 kg/h of feed solution (F) containing 20 wt% sugar is fed to an evaporator, which evaporates some water at 453K to produce 63 wt% of sugar solution. This solution is then fed to the first crystallizer (C_1) at 297K, where candy containing 73 wt% sugar is produced. In this first crystallizer, saturated solution containing 30 wt% sugar is recycled back to the evaporator. Next, the candy is fed to the second crystallizer (C_2) where candy containing 93 wt% sugar is produced. In this second crystallizer, saturated solution containing 30 wt% sugar is recycled back to the first crystallizer.

(i) Draw the mass balance diagram for the problem above.

(3 marks)

(ii) Calculate the mass flowrate of the output in the second crystallizer, C_2 in kg/h.

(4 marks)

(iii) Calculate the mass flow rate of the exit stream in the evaporator, E in kg/h.

(9 marks)

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Q4 (a) Define the following terms.

(i) Boundary

(ii) Recycle stream

(iii) Bypass stream

(6 marks)

(b) A desalination plant can supply 5,000 m^3 of freshwater per month. The seawater contains 94.5 wt% water, 3.5 wt% salt and 2 wt% of ultrafine sand particles. At the first stage of desalination process, 100 % the ultrafine sand particles will be removed via multi-media filters. The filtered seawater containing only water and salt will then is pressurized up to 1000 psi to allow the water pass though the reverse osmosis membranes to produce clean water (H_2O). However, the reverse osmosis process only able to convert 45 wt% of the seawater into pure water, while the 55 wt% of unrecovered water will be discharged together with the salt.

(i) State the component A, B and C for this process.

(3 marks)

(ii) Draw the mass balance diagram for this process.

(4 marks)

(iii) Determine the mass flow rate for all streams involved in this process in kg/month.

(7 marks)

Q5 (a) Define limiting and excess reactant.

(4 marks)

(b) Hexane (C_6H_{14}) at 535°C and 15 atm flows into the reactor at a rate of 3300 kg/h. Calculate the volumetric flowrate of this stream by using the conversion from standard conditons.

(6 marks)

(c) Calculate the ΔH^o for the following reaction:

$$H (g) + Br (g) \longrightarrow HBr (g)$$

Given the following information.

$$H_2 (g) \longrightarrow 2 H (g) \qquad \Delta H^o = 436.4 \text{ kJ}$$

$$Br_2 (g) \longrightarrow 2 Br (g) \qquad \Delta H^o = 192.5 \text{ kJ}$$

$$H_2 (g) + Br_2 (g) \longrightarrow 2HBr (g) \qquad \Delta H^o = -72.4 \text{ kJ}$$

(10 marks)

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Q6 (a) Define the terms below.

(i) Latent heat
(ii) Heat of fusion
(iii) Heat of vaporization

(6 marks)

(b) A stream of n-pentane are been heating from – 150°C until + 150°C in the separator.

(i) Construct a hypothetical path for this process.

(6 marks)

(ii) Determine the power required for this process.

(8 marks)

Q7 A 100 mol/s of benzene and toluene liquid at 50^{0}C is partially condensed out of a gas stream containing 85 mole% of benzene. The top product containing 90 mole% benzene and the bottom product is 56 mol/s containing only toluene liquid. Both products are coming out at 350°C.

(a) Draw the diagram for this process.

(6 marks)

(b) Determine the required heat cooling rate in kW.

(14 marks)

– END OF QUESTIONS –

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Formula

1 kg = 2.20462 lbm
1 meter = 3.28 ft
1 kg = 1000 g
1 meter = 100 cm
P_s = 1 atm, T_s = 273 K, V/n = 22.415 L/mol

$$\Delta H^o_{rxn} = \left[c\Delta H^o_f(C) + d\Delta H^o_f(D)\right] - \left[a\Delta H^o_f(A) + b\Delta H^o_f(B)\right]$$

$$\Delta H^o_{rxn} = \left[a\Delta H^o_f(A) + b\Delta H^o_f(B)\right] - \left[c\Delta H^o_f(C) + d\Delta H^o_f(D)\right]$$

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Compound	Formula	Mol. Wt.	SG (20°/4°)	T_m(°C)[b]	$\Delta\hat{H}_m(T_m)$[c,j] kJ/mol	T_b(°C)[d]	$\Delta\hat{H}_v(T_b)$[e,j] kJ/mol	T_c(K)[f]	P_c(atm)[g]	$(\Delta\hat{H}_f^\circ)$[h,j] kJ/mol	$(\Delta\hat{H}_c^\circ)$[i,j] kJ/mol
Acetaldehyde	CH_3CHO	44.05	$0.783^{18°}$	−123.7	—	20.2	25.1	461.0	—	−166.2(g)	−1192.4(g)
Acetic acid	CH_3COOH	60.05	1.049	16.6	12.09	118.2	24.39	594.8	57.1	−486.18(l) −438.15(g)	−871.69(l) −919.73(g)
Acetone	C_3H_6O	58.08	0.791	−95.0	5.69	56.0	30.2	508.0	47.0	−248.2(l) −216.7(g)	−1785.7(l) −1821.4(g)
Acetylene	C_2H_2	26.04	—	—	—	−81.5	17.6	309.5	61.6	+226.75(g)	−1299.6(g)
Ammonia	NH_3	17.03	—	−77.8	5.653	−33.43	23.351	405.5	111.3	−67.20(l) −46.19(g)	 −382.58(g)
Ammonium hydroxide	NH_4OH	35.03	—	—	—	—	—	—	—	−366.48(aq)	—
Ammonium nitrate	NH_4NO_3	80.05	$1.725^{25°}$	169.6	5.4		Decomposes at 210°C			−365.14(c) −399.36(aq)	—
Ammonium sulfate	$(NH_4)_2SO_4$	132.14	1.769	513	—		Decomposes at 513°C after melting			−1179.3(c) −1173.1(aq)	
Aniline	C_6H_7N	93.12	1.022	−6.3	—	184.2	—	699	52.4	—	—
Benzaldehyde	C_6H_5CHO	106.12	1.046	−26.0	—	179.0	38.40	—	—	−88.83(l) −40.04(g)	−3520.0(l) —
Benzene	C_6H_6	78.11	0.879	5.53	9.837	80.10	30.765	562.6	48.6	+48.66(l) +82.93(g)	−3267.6(l) −3301.5(g)
Benzoic acid	$C_7H_6O_2$	122.12	$1.266^{15°}$	122.2	—	249.8	—	—	—	—	−3226.7(g)
Benzyl alcohol	C_7H_8O	108.13	1.045	−15.4	—	205.2	—	—	—	—	−3741.8(l)
Bromine	Br_2	159.83	3.119	−7.4	10.8	58.6	31.0	584	102	0(l)	—
1,2-Butadiene	C_4H_6	54.09	—	−136.5	—	10.1	—	446	—	—	—
1,3-Butadiene	C_4H_6	54.09	—	−109.1	—	−4.6	—	425	42.7	—	—
n-Butane	C_4H_{10}	58.12	—	−138.3	4.661	−0.6	22.305	425.17	37.47	−147.0(l) −124.7(g)	−2855.6(l) −2878.5(g)
Isobutane	C_4H_{10}	58.12	—	−159.6	4.540	−11.73	21.292	408.1	36.0	−158.4(l) −134.5(g)	−2849.0(l) −2868.8(g)
1-Butene	C_4H_8	56.10	—	−185.3	3.8480	−6.25	21.916	419.6	39.7	+1.17(g)	−2718.6(g)
Calcium carbide	CaC_2	64.10	$2.22^{18°}$	2300	—	—	—	—	—	−62.76(c)	—
Calcium carbonate	$CaCO_3$	100.09	2.93			Decomposes at 825°C				−1206.9(c)	—
Calcium chloride	$CaCl_2$	110.99	$2.152^{15°}$	782	28.37	>1600	—	—	—	−794.96(c)	—

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Compound	Formula	Mol. Wt.	SG (20°/4°)	T_m(°C)[b]	$\Delta\hat{H}_m(T_m)$[c,j] kJ/mol	T_b(°C)[d]	$\Delta\hat{H}_v(T_b)$[e,j] kJ/mol	T_c(K)[f]	P_c(atm)[g]	$(\Delta\hat{H}_f^\circ)$[h,j] kJ/mol	$(\Delta\hat{H}_c^\circ)$[i,j] kJ/mol
Methyl ethyl ketone	C_4H_8O	72.10	0.805	−87.1	—	78.2	32.0	—	—	—	−2436(l)
Naphthalene	$C_{10}H_8$	128.16	1.145	80.0	—	217.8	—	—	—	—	−5157(g)
Nickel	Ni	58.69	8.90	1452	—	2900	—	—	—	0(c)	—
Nitric acid	HNO_3	63.02	1.502	−41.6	10.47	86	30.30	—	—	−173.23(l) −206.57(aq)	—
Nitrobenzene	$C_6H_5O_2N$	123.11	1.203	5.5	—	210.7	—	—	—	—	−3092.8(l)
Nitrogen	N_2	28.02	—	−210.0	0.720	−195.8	5.577	126.20	33.5	0(g)	—
Nitrogen dioxide	NO_2	46.01	—	−9.3	7.335	21.3	14.73	431.0	100.0	+33.8(g)	—
Nitric oxide	NO	30.01	—	−163.6	2.301	−151.8	13.78	179.20	65.0	+90.37(g)	—
Nitrogen pentoxide	N_2O_5	108.02	$1.63^{18°}$	30	—	47	—	—	—	—	—
Nitrogen tetraoxide	N_2O_4	92.0	1.448	−9.5	—	21.1	—	431.0	99.0	+9.3(g)	—
Nitrous oxide	N_2O	44.02	$1.226^{-89°}$	−91.1	—	−88.8	—	309.5	71.70	+81.5(g)	—
n-Nonane	C_9H_{20}	128.25	0.718	−53.8	—	150.6	—	595	23.0	−229.0(l) —	−6124.5(l) −6171.0(g)
n-Octane	C_8H_{18}	114.22	0.703	−57.0	—	125.5	—	568.8	24.5	−249.9(l) −208.4(g)	−5470.7(l) −5512.2(g)
Oxalic acid	$C_2H_2O_4$	90.04	1.90	Decomposes at 186°C				—	—	−826.8(c)	−251.9(s)
Oxygen	O_2	32.00	—	−218.75	0.444	−182.97	6.82	154.4	49.7	0(g)	—
n-Pentane	C_5H_{12}	72.15	$0.63^{18°}$	−129.6	8.393	36.07	25.77	469.80	33.3	−173.0(l) −146.4(g)	−3509.5(l) −3536.1(g)
Isopentane	C_5H_{12}	72.15	$0.62^{19°}$	−160.1	—	27.7	— —	461.00	32.9	−179.3(l) −152.0(g)	−3507.5(l) −3529.2(g)
1-Pentene	C_5H_{10}	70.13	0.641	−165.2	4.94	29.97		474	39.9	−20.9(g)	−3375.8(g)
Phenol	C_6H_5OH	94.11	$1.071^{25°}$	42.5	11.43	181.4	—	692.1	60.5	−158.1(l) −90.8(g)	−3063.5(s) —
Phosphoric acid	H_3PO_4	98.00	$1.834^{18°}$	42.3	10.54	$(-\frac{1}{2}H_2O$ at 213°C)		—	—	−1281.1(c) −1278.6(aq, $1H_2O$)	— —
Phosphorus (red)	P_4	123.90	2.20	$590^{43 \text{ atm}}$	81.17	Ignites in air, 725°C		—	—	−17.6(c) 0(c)	—

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Form 1: C_p[kJ/(mol·°C)] or [kJ/(mol·K)] = $a + bT + cT^2 + dT^3$
Form 2: C_p[kJ/(mol·°C)] or [kJ/(mol·K)] = $a + bT + cT^{-2}$

Example: $(C_p)_{acetone(g)} = 0.07196 + (20.10 \times 10^{-5})T - (12.78 \times 10^{-8})T^2 + (34.76 \times 10^{-12})T^3$, where T is in °C.

Note: The formulas for gases are strictly applicable at pressures low enough for the ideal gas equation of state to apply.

Compound	Formula	Mol. Wt.	State	Form	Temp. Unit	$a \times 10^3$	$b \times 10^5$	$c \times 10^8$	$d \times 10^{12}$	Range (Units of T)
Acetone	CH_3COCH_3	58.08	l	1	°C	123.0	18.6			−30–60
			g	1	°C	71.96	20.10	−12.78	34.76	0–1200
Acetylene	C_2H_2	26.04	g	1	°C	42.43	6.053	−5.033	18.20	0–1200
Air		29.0	g	1	°C	28.94	0.4147	0.3191	−1.965	0–1500
			g	1	K	28.09	0.1965	0.4799	−1.965	273–1800
Ammonia	NH_3	17.03	g	1	°C	35.15	2.954	0.4421	−6.686	0–1200
Ammonium sulfate	$(NH_4)_2SO_4$	132.15	c	1	K	215.9				275–328
Benzene	C_6H_6	78.11	l	1	°C	126.5	23.4			6–67
			g	1	°C	74.06	32.95	−25.20	77.57	0–1200
Isobutane	C_4H_{10}	58.12	g	1	°C	89.46	30.13	−18.91	49.87	0–1200
n-Butane	C_4H_{10}	58.12	g	1	°C	92.30	27.88	−15.47	34.98	0–1200
Isobutene	C_4H_8	56.10	g	1	°C	82.88	25.64	−17.27	50.50	0–1200
Calcium carbide	CaC_2	64.10	c	2	K	68.62	1.19	-8.66×10^{10}	—	298–720
Calcium carbonate	$CaCO_3$	100.09	c	2	K	82.34	4.975	-12.87×10^{10}	—	273–1033
Calcium hydroxide	$Ca(OH)_2$	74.10	c	1	K	89.5				276–373
Calcium oxide	CaO	56.08	c	2	K	41.84	2.03	-4.52×10^{10}		273–1173
Carbon	C	12.01	c	2	K	11.18	1.095	-4.891×10^{10}		273–1373
Carbon dioxide	CO_2	44.01	g	1	°C	36.11	4.233	−2.887	7.464	0–1500
Carbon monoxide	CO	28.01	g	1	°C	28.95	0.4110	0.3548	−2.220	0–1500
Carbon tetrachloride	CCl_4	153.84	l	1	K	93.39	12.98			273–343
Chlorine	Cl_2	70.91	g	1	°C	33.60	1.367	−1.607	6.473	0–1200
Copper	Cu	63.54	c	1	K	22.76	0.6117			273–1357
Nitrogen	N_2	28.02	g	1	°C	29.00	0.2199	0.5723	−2.871	0–1500
Nitrogen dioxide	NO_2	46.01	g	1	°C	36.07	3.97	−2.88	7.87	0–1200
Nitrogen tetraoxide	N_2O_4	92.02	g	1	°C	75.7	12.5	−11.3		0–300
Nitrous oxide	N_2O	44.02	g	1	°C	37.66	4.151	−2.694	10.57	0–1200
Oxygen	O_2	32.00	g	1	°C	29.10	1.158	−0.6076	1.311	0–1500
n-Pentane	C_5H_{12}	72.15	l	1	°C	155.4	43.68			0–36
			g	1	°C	114.8	34.09	−18.99	42.26	0–1200
Propane	C_3H_8	44.09	g	1	°C	68.032	22.59	−13.11	31.71	0–1200
Propylene	C_3H_6	42.08	g	1	°C	59.580	17.71	−10.17	24.60	0–1200
Sodium carbonate	Na_2CO_3	105.99	c	1	K	121				288–371
Sodium carbonate decahydrate	$Na_2CO_3 \cdot 10H_2O$	286.15	c	1	K	535.6				298
Sulfur	S	32.07	c (Rhombic)	1	K	15.2	2.68			273–368
			c (Monoclinic)	1	K	18.3	1.84			368–392
Sulfuric acid	H_2SO_4	98.08	l	1	°C	139.1	15.59			10–45
Sulfur dioxide	SO_2	64.07	g	1	°C	38.91	3.904	−3.104	8.606	0–1500
Sulfur trioxide	SO_3	80.07	g	1	°C	48.50	9.188	−8.540	32.40	0–1000
Toluene	C_7H_8	92.13	l	1	°C	148.8	32.4			0–110
			g	1	°C	94.18	38.00	−27.86	80.33	0–1200
Water	H_2O	18.016	l	1	°C	75.4				0–100
			g	1	°C	33.46	0.6880	0.7604	−3.593	0–1500

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